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Author for correspondence:

Sirpa Rasmus, Email: sirpa.rasmus@ulapland.fi

^aFirst author: bforbes@ulapland.fi

Changes in mountain birch forests and reindeer management: Comparing different knowledge systems in Sápmi, northern Fennoscandia

Bruce C. Forbes^{1,a}, Minna T. Turunen¹, Päivi Soppela¹, Sirpa Rasmus¹ , Terhi Vuojala-Magga¹ and Heidi Kitti²

¹Arctic Centre, University of Lapland, Rovaniemi, Finland and ²Saami Regional Education Centre, Inari, Finland

Abstract

Mountain birch forests in the northern areas of Sápmi, the Saami homeland, serve as pastures for semi-domesticated reindeer. Recent reindeer management of the area has, to date, proceeded with little involvement of reindeer herders or their knowledge. To get more in-depth understanding of recent changes, we present together herders' knowledge and scientific knowledge concerning the impacts of herbivory and climate change on mountain birch forests in three Saami communities in Norway and in Finland. Most of the herders interviewed reported changes in weather during the preceding decades. Herders agreed that the canopy and understorey of mountain birch forests have changed. The observed transformations in the quality of pastures have increased the financial costs of reindeer husbandry. Our study demonstrates that herders have practical knowledge of the present state and recent changes of birch forests, and of the responses of reindeer caused by these. This knowledge generally coincides with scientific knowledge. We call for better integration of knowledge systems and a better protocol for co-production of knowledge as it relates to more adaptive future reindeer management regimes. Such integration will facilitate understanding of cultural adaptation within rapidly changing social-ecological systems in which sustainable reindeer husbandry continues to be an important livelihood.

Introduction

Mountain birch (*Betula pubescens* spp. *czerepanovii*) is the predominant tree within the sub-arctic forest zone of northern Fennoscandia, which is situated between treeless upland fells and the coniferous forest zone at lower elevations (Fig. 1). As such, the mountain birch forest ecosystems are the most important source of primary production in the northern areas of Sápmi, the Saami homeland that encompasses much of northern Fennoscandia, including parts of Kola Peninsula (Lehtola, 2002; Wielgolaski, 2002).

Indigenous Saami have used mountain birch forests for several centuries in various ways: as a pasture for semi-domesticated reindeer (*Rangifer tarandus tarandus*) and for hunting, trapping, fishing, food and fuel gathering, raw material for handicrafts and construction, and also for spiritual purposes (Aikio & Müller-Wille, 2002; Crate, Forbes, King, & Kruse, 2010; Itonen, 1984). The mountain birch region is utilised also by other inhabitants of the area and it serves as an important resource for recreation and for land uses like tourism and wind power. Mountain birch forests are cultural landscapes; intensity and spatial distribution of land uses, specifically reindeer grazing, has been shaped by cultural activities and socio-political processes for centuries (Bernes, Bråthen, Forbes, Speed, & Moen, 2015; Uboni et al., 2016).

Mountain birch is an important source of summer forage for reindeer; during winter reindeer feed mainly on the terricolous lichens, as well as dwarf shrubs, that grow on the forest floor. Access to winter forage is often difficult and energy expenditure of moving and foraging is increased, due to snow conditions (Kitti, Gunsley, & Forbes, 2006; Riseth et al., 2011). Deep or icy snow during the winter or late snow melt during the following spring may lead to high winter mortality of reindeer as well as to low calf survival (Eira, 2012; Kitt et al., 2006; Turunen, Rasmus, Bavay, Ruosteenoja, & Heiskanen, 2016). As high latitudes warm, more frequent formation of ice crusts in the snow cover is expected (Meredit et al., 2019; Rasmus, Kivinen, Bavay, & Heiskanen, 2016). When the snow cover is deep or icy, reindeer look for the arboreal lichens that grow on the upper trunks and branches of birch (Sonesson, 2001).

In addition to accessibility of forage, the state of the understorey vegetation (ground lichen, graminoids and shrubs) is crucial when considering mountain birch forests as reindeer pastures. Herbivory and climate are considered as main factors affecting the mountain birch forests ecosystems of the region (Cairns, Lafon, Moen, & Young, 2007; Moen, Cairns, & Lafon, 2008; Tømmervik et al., 2004; Wielgolaski, 2002). Reindeer themselves affect soil properties

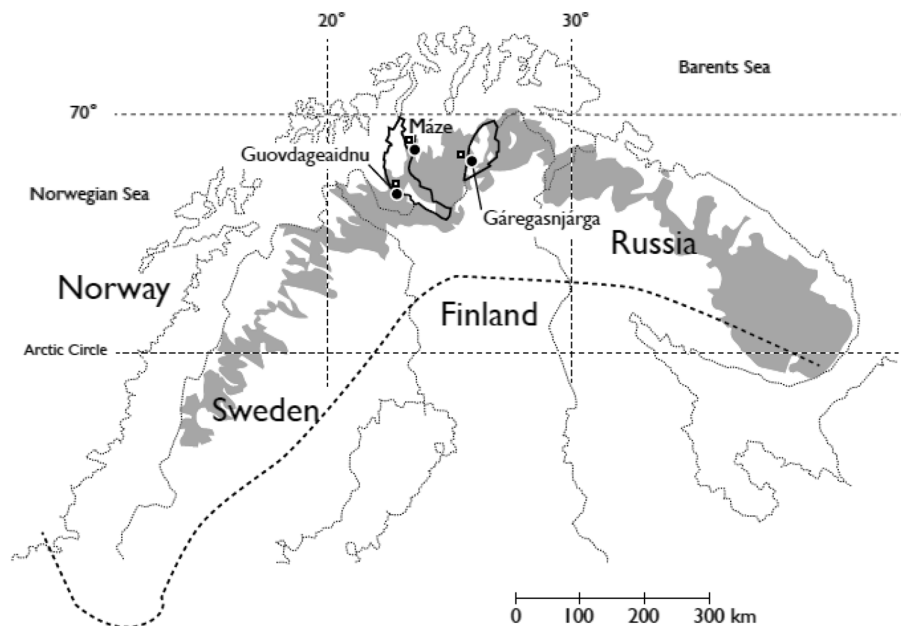


Fig. 1. Northern Fennoscandia and Sápmi (dashed line, Lehtola, 2002). Research communities of Máze, Guovdageaidnu and Gáregasnjárga are marked, and the solid black lines mark the herding districts of the communities (Guovdajohtolat in Norway and Báisiđuottar in Finland). The mountain birch ecoregion of northern Fennoscandia is shaded in the map. Area used by reindeer stretches also south, outside Sápmi (Johansen unpublished; Käyhkö & Horstkotte, 2017). White squares mark the meteorological stations of Guovdageaidnu, Suolovuopmi and Kárášjohka (Karasjok).

and microbial processes, plant species and vegetation diversity by grazing, trampling and through excrements (Bernes *et al.*, 2015; Väisänen *et al.*, 2014). Geometrid moths including autumnal (*Epirrita autumnata*) and winter moths (*Operophtera brumata*) have periodically great effect on the mountain birch (Helle, 2001; Neuvonen, Bylund, & Tømmervik, 2005; Fig. 2). Other herbivores (voles, lemmings and some invertebrates) (Anschlag, Broll, & Holtmeier, 2008), fire (Stocks *et al.*, 1998), forest cutting (Veijola, 1998) and tourism (Forbes, Tolvanen, Wielgolaski, & Laine, 2005) also affect these ecosystems.

Autumnal moths appear episodically at approximately 10-year intervals (Tenow & Nilssen, 1990). A severe autumnal moth outbreak was experienced in our research area in 1965–66; significant outbreaks have been documented also in 1927 and 1955 (Kallio & Lehtonen, 1973). In the 1960s, autumnal moths defoliated sizeable areas of mountain birch forest in Ohcejohka commune in northernmost Finland; these areas have regenerated extremely slowly over the intervening five decades and are presently mostly treeless tundra (Neuvonen *et al.*, 2005). During the years 2002–2008, both autumnal and winter moths caused spatially variable defoliation within the region (Jepsen, Hagen, Ims, & Yoccoz, 2008; Klemola, Andersson, & Ruohomäki, 2016).

Studies in Arctic North America and northwest Eurasia have indicated an increase in tall deciduous shrub cover and abundance in response to climate change (Forbes, Macias-Fauria, & Zetterberg, 2010; Macias-Fauria, Forbes, Zetterberg, & Kumpula, 2012; Myers-Smith *et al.*, 2011; Tape, Sturm, & Racine, 2006; Tømmervik *et al.* 2004). Higher temperature and increased precipitation are favourable for seed production of birch trees near the tree line (Wielgolaski, 2002). In the past, the tree line has migrated further north and to higher elevations when air temperatures have been high enough (Kullman, 2002). The effects of climate change on the mountain birch tree line can be difficult to isolate from other factors that affect

it simultaneously (Emanuelsson, 1987; Hofgaard, 1997). For example, in northern Sweden, reindeer grazing keeps landscapes open and controls the deciduous tree line (Cairns & Moen, 2004).

In this work we relate two different knowledge systems, scientific knowledge and practitioners' knowledge of local herders, to gain more in-depth understanding of the recent changes in the mountain birch forests of our research area. Scientific knowledge is accumulated through a formalised process and is most often explicit (written) and quantitative. Ecological and meteorological research is based on measurements (observations, monitoring, remote sensing), retrospective analyses, experimental manipulation of environment or on mathematical modelling. It aims at generalisations, replicability and objectivity (Huntington, Callaghan, Fox, & Krupnik, 2004; Raymond *et al.*, 2010). In recent decades, a large and fast-growing body of literature has addressed the cultures carrying Indigenous Knowledge, Traditional Knowledge and Traditional Ecological Knowledge (TEK) (e.g. Agrawal, 1995; Alexander *et al.*, 2011). The commonly used term TEK can be defined as "knowledge, practice and beliefs about the dynamic relationship of living beings with one another, and with their environment, which has evolved by adaptive processes, and has been handed down from generation to generation" (Berkes, 2008). In our case TEK can be understood as local, *practitioners' knowledge* possessed by herders. Local knowledge is a wide term including several knowledge systems, also those classified as traditional and indigenous. It is thought to be developed by societies with long histories of interaction with their natural surroundings but it is not confined to certain inhabitant groups of the area (FAO, 2017; UNESCO, 2017). Also practitioners' knowledge widens the scope of TEK to acknowledge the non-ethnic nature of knowledge gained in certain livelihoods by spending time on the land and evolving knowledge through practice and experience (Ingold, 2000). This knowledge has been gained over decades, most often

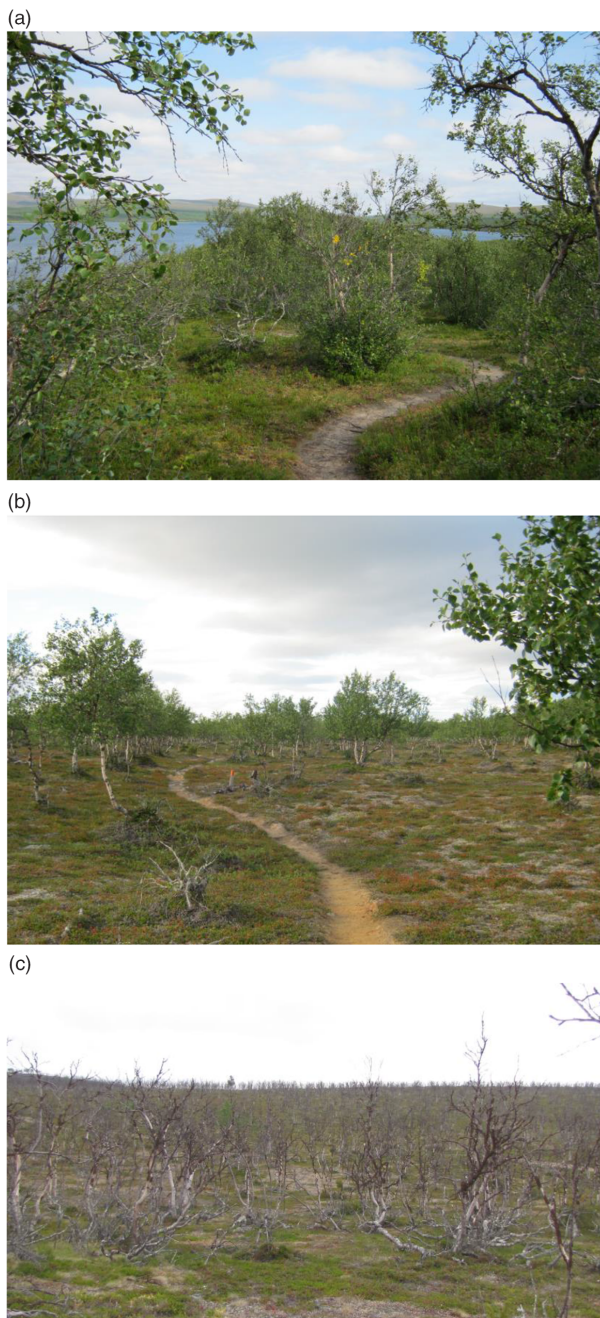


Fig. 2. Mountain birch forest before an autumnal moth outbreak without (a) and with (b) intensive reindeer herbivory, and after the outbreak (c). Photos: Otso Suominen.

since childhood, and reflected in local practices (Forbes, 2006; Helander-Renvall, 2014; Vuojala-Magga, Turunen, Ryyppö, & Tennberg, 2011).

Practitioners' knowledge of local herders has only relatively recently been integrated into studies on the status and management of mountain birch forests. Themes covered range from mountain birch forests as reindeer pastures (Aikio & Müller-Wille, 2002; Inga, 2007; Kitti et al., 2006; Vuojala-Magga & Turunen, 2015) to vegetation dynamics within the area (Horstkotte et al., 2017; Huntington et al., 2004). Also, the roles of extreme weather events

(Vuojala-Magga et al., 2011) and snow conditions (Eira et al., 2013; Riseth et al., 2011) in herding have been discussed.

The understanding gained through relating different knowledge systems is especially needed in the planning of the northern land use and the management of reindeer herds. The post-WWII management regimes of reindeer herds within the respective Nordic countries have adhered to increasingly strict agricultural norms geared to maximise meat production, and while sustaining ground lichen reserves within winter pastures (Forbes, 2006; Forbes & Stammler, 2009). This approach has, to date, proceeded with little to no involvement of herders or their knowledge (Heikkinen, Sarkki, & Nuttall, 2012; Sarkki, Heikkinen, Herva, & Saarinen, 2018). This contrasts with the situation in Arctic North America, where co-management of renewable resources has been legally codified since the 1970s (Forbes & Stammler, 2009). Participatory action research, in which stakeholders and scientists collaborate and reflect on research implementation and interpretation, is relatively new in Nordic reindeer management (Hukkinen et al., 2006). As recently as 15 years ago, research directly involving reindeer herders was deemed too "political" in Finland (Kitti, 2004), and the admission of access to an area of science by "primitive and illiterate reindeer herders" (Magga, 2006) was disapproved. Since then, however, participatory approaches to connect science, policy and society have become increasingly common (Armitage, Berkes, Dale, Kocho-Schellenberg, & Patton, 2011; Nilsson et al., 2019). New types of participatory methods are developing into a new norm in Nordic Arctic renewable resource management (Adenskog, 2018; Huntington et al., 2019; Jäske, 2018); participatory decision-making is believed to lead to more long-term, deliberate, inclusive and sustainable governance solutions. Emphasis on participation has been established as a general frame also in research funding (Armitage et al., 2011). Both national and EU Arctic strategies (European Commission, 2016; Prime Minister's Office, 2013) have been developed to explicitly engage local stakeholders in research projects and land use planning processes. All of these developments call for research that is participatory, acknowledging the characteristics and potential of different knowledge systems.

This study is intended as a contribution towards the integration of distinct knowledge systems in Nordic mountain birch forests in the service of developing a better protocol for co-production of knowledge as it relates to more adaptive future reindeer management regimes. Our overall aim is to understand how the mountain birch forests dynamics are perceived, respectively, in reindeer herders' and scientific knowledge systems. Specifically, we concentrate on knowledge pertaining to potential pathways from relatively closed mountain birch forest to open tundra, following massive herbivorous moth outbreaks in three localities within the Saami reindeer management region. To do so, we have collected the scientific and practitioners' "ways of knowing" (*sensu* Kendrick, 2003) relevant to such moth outbreaks and describe the processes underlying the disappearance and regeneration, where relevant, of mountain birch forests, which function as reindeer rangelands. The main objectives are therefore to:

- (1) assess herders' perceptions of the key ecological drivers of birch forest rangeland dynamics following massive herbivorous moth outbreaks;
- (2) present together herders' perceptions of change and relevant findings within the scientific literature; and
- (3) discuss the potential for future integration of practitioners' knowledge in reindeer management regimes of Sápmi.

Table 1. Characteristics and mean climate conditions¹ of the research communities

	Gáregasnjárga, Finland	Máze, Norway	Guovdageaidnu, Norway
Coordinates	69° 23'54"N 25° 51' 18"E	69°26'37"N 23°40'01"E	69° 0'43"N 23° 2'37"E
Municipality (area/inhabitants)	Ohcejohka (5370 km ² /1300)	Guovdageaidnu (9707 km ² /3000)	Guovdageaidnu (9707 km ² /3000)
Elevation (m.a.s.l.)	140	282	319
Reindeer herding district ² (reindeer/herders)	Báišduottar (6943/102)	Guovdajohtolat (33980/745)	Guovdajohtolat (33980/745)
Reindeer density (reindeer km ⁻²)	2.2	3.0	3.0
Mean annual temperature (°C)	−2.3	−2.4	−2.5
Mean annual precipitation (mm)	384	456	494

¹Data for Máze from meteorological station of Suolovuopmi (381 m.a.s.l., 19 km away) and for Gáregasnjárga from station of Kárášjohka (129 m.a.s.l., 19 km away).

²Administrative units of reindeer management; their organisation and activities are guided by the law. Village of Guovdageaidnu is situated at the western border of the herding district Guovdajohtolat (Kautokeino midtre sone) and the district Oarjabealli (Kautokeino Vestre sone). Village of Máze is situated close to the eastern border of the district Guovdajohtolat. Village of Gáregasnjárga is located in the district Báišduottar (Paistunturi). Reindeer data are for the year 2015–2016, Finland from RHA (2017) and Norway from Landbruksdepartementet (2016).

Material and methods

Research area

The research area included the Saami communities of Máze (Masi) and Guovdageaidnu (Kautokeino) in Norway and Gáregasnjárga (Karigasniemi) in Finland (Fig. 1, Table 1). They are all situated within the sub-arctic zone; seasonal snow cover forms in the area typically in October and melts in May. The dominant tree in the area is mountain birch. The villages of Máze and Guovdageaidnu are located in Guovdajohtolat herding district, and in Guovdageaidnu (Kautokeino) municipality in Finnmark county; it is the largest municipality in Norway. Máze has approximately 400 inhabitants and about 1300 people live in Guovdageaidnu. Gáregasnjárga is located in the Báišduottar herding district, and in Ohcejohka (Utsjoki) municipality; it has about 300 inhabitants. In the municipality of Ohcejohka, more than half of the inhabitants speak Saami as their native tongue and in the Guovdageaidnu municipality over 90%.

In each village, reindeer husbandry is an important livelihood; the surrounding territories serve as reindeer pastures, and 8–25% of the inhabitants of the Ohcejohka and Guovdageaidnu municipalities are reindeer herders (see Table 1). There are also other land users, for example tourism, of which the most important form is moose (*Alces alces* L.) hunting. Herding practices of the area are based on Saami tradition. In this tradition (compared to small-scale herding combined with other livelihoods, practised in more southern, forested herding districts of Finland) herds are bigger, herding is more often based on pastoralism, and intensive supplementary winter feeding, especially feeding in enclosures, is seldom used (Helle and Jaakkola, 2008; Kittí et al., 2006). Herding work is organised through herding groups, *siidas* (Vuojala-Magga, 2012). Differences nevertheless exist between the practices of the herding communities. In northern Norway, reindeer generally move long distances between their summer and winter pastures. In Guovdageaidnu and Máze the winter pasture areas are situated inland, where lichen heaths dominate and summer pastures are by the sea, where vegetation consists of herbs and shrubs and there are also fewer biting insects

compared to more heavily forested inland pastures. This represents a natural seasonal pasture rotation for reindeer. In difficult years (deep snow, icing of the ground), reindeer are given supplemental winter feed. The vicinities of the villages of Guovdageaidnu and Máze are utilised as transitional autumn/spring pastures. In Gáregasnjárga, Finland, reindeer graze more or less on the same areas year-round, even though some areas are protected from summer trampling. Annual slaughtering is nowadays conducted in autumn; this practice protects lichens pastures since fewer animals remain alive to forage throughout the winter. The reindeer have been herded with the aid of supplemental feeding (i.e. provided with forage along the way from one pasture area to another) in late winter since the 1990s. This practice is intended to reduce natural mortality, especially of pregnant females, during winters with deep or icy snow and maintain relatively consistent calf birth rates and weights from year to year. Detailed descriptions of the mountain birch forests of the research area are found in Neuvonen et al. (2005) and in Vuojala-Magga & Turunen (2015), of meteorological conditions in Vikhamar-Schuler, Hanssen-Bauer, & Førland (2010) and in Rasmus et al. (2014), and of reindeer population dynamics in Uboni et al. (2016).

Knowledge systems on the impacts of herbivory and climate change on mountain birch forests

Interview methods

Semi-directed interviews were conducted with altogether 22 reindeer herders during 2007–2008. This comprises approximately 2.6 % of the herders of the Báišduottar and Guovdajohtolat herding districts (Table 1). Ten herders were interviewed in Gáregasnjárga, nine in Máze and three in Guovdageaidnu. We knew most of the herders beforehand in Gáregasnjárga, but not in Máze and Guovdageaidnu. One of us lived in two different families altogether one month. The interactions between the researchers and informants were thus not only based on interviews but on a mutual trust due to shared living experience. Participant observation transitioned to thematic interviews. Informants were found through the “snowball-method”

meaning that we asked each informant whom we should interview next. For interviews, we adhered to the research principles of the International Arctic Social Sciences Association (IASSA, 1998). The informants, all adults, consented to be interviewed and have approved the information and the sharing of it publicly, albeit anonymously. Sixteen of the herders were men and six were women. Their ages varied between 30 and 75 years, but most of them were 60–70 years old. People from different age groups were interviewed to obtain a broad sample set among the active and retired herders. The interviews were conducted either in Saami or in Finnish by two biologists and an anthropologist. It was an advantage that most of the participant observation and interviews could be conducted in Saami as this was the native language of most of the informants. In this paper, we present some Saami terms related to phenomena discussed when appropriate, but we do not present comprehensive analogues for all terminologies used. Saami terminology is designated via the use of italics throughout the text. The interviews were thematic, enabling the discussion of matters that the herders found interesting and important. As starting questions the herders were asked about the main characteristics of their pastures (e.g. topography, vegetation and the significance of mountain birch forests), their management practices, effects of geometrid moths, reindeer foraging and variation in weather on the amount and accessibility of forage on the pastures, and effects of these on reindeer husbandry. Subsequent to this step, discussions were left unstructured, but followed the themes which came naturally up. The temporal perspective of the processes discussed varied according to the theme: variation of weather was most often considered during the last 10–20 years, but for moth outbreaks and other rare events the time perspective was approximately 50 years.

The interview material was gone through and analysed thematically using a qualitative content analysis approach (Krippendorff, 1980). We sought to gain an interpretive understanding of the material, making comparison with scientific knowledge possible. From the material arose two central themes: changes in winter weather during recent decades, and changes in vegetation and effects of herbivory on reindeer pastures. Subthemes were: implications of changes in winter weather for reindeer husbandry; changes in birch forests; changes in understorey vegetation; effects of the moth outbreaks; and effects of reindeer grazing. Material related to these compiles the practitioners' knowledge set used in this study. To protect the privacy of the informants, each person was assigned a code. Informants in Gáregasnjárga have codes G1–G10, in Máze the codes are M1–M9 and in Guovdageaidnu the codes are GG1–GG3. Letters without numbers (G, M, GG) refer to the reindeer herders of each village in general. Excerpts from 13 interviews are quoted in the text.

Literature review methods

Results of a complete meta-analysis of all studies on drivers of reindeer rangeland dynamics in northern Fennoscandia would not be commensurate with the practitioners' knowledge described above and would not allow relevant comparison. Scientific knowledge concerning the central themes of the interviews was therefore compiled through a targeted literature review. A standard internet search using Google Scholar was performed from the recent literature starting with the broadest possible search terms. The main search terms were *Betula pubescens* spp. *czerepanovii* (or simply *Betula pubescens*) and mountain birch forest (or simply mountain birch). The approach was therefore comparable to the

"snowball-method" utilised in the herders' interviews (see Interview methods above), in that if a publication's bibliography contained seemingly relevant citations, then those older publications would be checked as well. The time frame was eventually selected as the 1970s, when the outcomes of major moth outbreaks relevant for our study were first reported, up to the present. After the first step, publications were discarded if they were based on *B. pubescens* woodlands outside the geographical area of the study (e.g. Greenland, Iceland or central Norway). Similarly, if the study did not address central themes of the interviews (see Interview methods above), it was excluded. The publication types included in our review were peer-reviewed papers, book chapters and scientific reports. The literature search was performed both in English and Finnish. Approximately 200 references were screened, and about 80 cited. Of these, altogether 40 locally relevant references comprise the core of the scientific knowledge used in this study. The main results of these publications are collected in Tables 2 and 4, together with herders' knowledge on central themes of the interviews. We compared the different knowledge systems both according to consideration of certain phenomena or process (has the issue been discussed?), and also according to the considered substance (i.e. coincidence of the knowledge systems; Huntington et al., 2004). Knowledge gaps and inconsistencies between the knowledge systems were also mapped.

Results

In this section, we go through the themes of the study, beginning by presenting herders' experiences, based on interviews. These results are then discussed in the light of previous studies. See Tables 2 and 4 for summaries comparing herders' knowledge and scientific knowledge concerning the changes in winter weather, and the changes in the vegetation cover in the research area, respectively.

Changes in winter weather during recent decades

Most of the herders reported specific changes in winter weather during the last 10–20 years (Table 2). Herders said that forecasting weather has become increasingly difficult and that weather changes more quickly. It has become more common even in midwinter that first it is raining and the next day the temperature is below 0°C. There are more often episodes of thawing (*njáhcui*) in midwinter, as well as extended periods of mild weather with a concomitant reduction in long periods of freezing temperatures (GG2). "For example, we were herding reindeer during Christmas 2007 and it was incomplete snow cover (*girjebievla*)" (GG2). Herders observe the quality and quantity of snow to estimate the conditions for moving, access to forage and herding (Eira et al., 2013). The Saami snow concept *goavvi* relates to extremely poor grazing conditions due to deep or icy snow. According to herders, icing of the ground (*bodneskártta*) has become more frequent, as well as ice layers (*geartnit*) within the snow column. Herders have observed delayed snow cover formation in the autumn and earlier snowmelt in the spring.

Herders' observations about warmer winters and shortened periods below 0°C coincide with the measurements of long-term climate trends for the Guovdageaidnu area (Vikhamar-Schuler et al., 2010, 2016) and northern Finland (Lépy & Pasanen, 2017; Vuojala-Magga et al., 2011). Delayed snow cover formation has been observed in some meteorological stations of the area by Rasmus et al. (2014), but Vikhamar-Schuler et al. (2010) observed

Table 2. Comparison of herders' knowledge and scientific knowledge concerning the changes in weather during the last decades in the research area

Herders' observations	Scientific knowledge	Reference
More variable weather	No data	
Warmer winters, long periods of freezing temperatures reduced, thaw in midwinter more common (GG)	Number of days <−15°C decreased, no change in mean winter temperature. Number of days <−35 °C decreased. Exceptionally warm winter periods more common. Shorter season with below 0°C temperatures, decline in extremely cold days. Winters less severe (negative sum of degree days decreased).	Vikhamar-Schuler <i>et al.</i> (2010)** Vuojala-Magga <i>et al.</i> (2011)** Vikhamar-Schuler <i>et al.</i> (2016)** Kivinen <i>et al.</i> (2017)** Lépy and Pasanen (2017)*
Ice-crusts snow layers more common (GG)	No change in number of rain-on-snow events after a cold period. More frequent ice formation in the snow cover. Exceptionally warm winter periods with melt or precipitation more common. Number of freeze-thaw cycles increased.	Vikhamar-Schuler <i>et al.</i> (2010)** Eira (2012)** Vikhamar-Schuler <i>et al.</i> (2016)** Lépy and Pasanen (2017)*
Ground ice more common (GG)	No change in number of black frost days ¹ . More frequent ice formation in the snow cover. Exceptionally warm winter periods with melt or precipitation more common. Increase in extremely warm events during autumn, leading to higher risk of ground ice.	Vikhamar-Schuler <i>et al.</i> (2010)** Eira (2012)** Vikhamar-Schuler <i>et al.</i> (2016)** Kivinen <i>et al.</i> (2017)**
Thinner early winter snow covers (GG)	Snow season duration shorter, no change in the first day of snow season. Later snow formation. Snow cover duration shorter.	Vikhamar-Schuler <i>et al.</i> (2010)** Rasmus <i>et al.</i> (2014)** Lépy and Pasanen (2017)*
Deep snow cover forms later during the winter (GG)	No change in max annual snow cover. No significant change in max annual snow cover. No significant change in snow cover depth.	Vikhamar-Schuler <i>et al.</i> (2010)** Rasmus <i>et al.</i> (2014)** Lépy and Pasanen (2017)*
Snow melts earlier (G)	Higher mean spring temperatures, earlier snow melt. Earlier snow melt Snow cover duration shorter.	Vikhamar-Schuler <i>et al.</i> (2010)** Vuojala-Magga <i>et al.</i> (2011)** Kivinen <i>et al.</i> (2017)** Rasmus <i>et al.</i> (2014)** Lépy and Pasanen (2017)*

¹Periods with snow-free ground and air temperature below 0°C during 1 September–31 August.

References to scientific literature have been sorted according to the local relevance, ** meaning high relevance (studies conducted in the same locations than our interviews) and * meaning some relevance (studies conducted in the northern Fennoscandian mountain birch region).

no significant change in the first day of the snow season. Studies have not observed significant changes in the maximum annual snow depth of the area (Rasmus *et al.*, 2014; Lépy and Pasanen 2017; Vikhamar-Schuler *et al.*, 2010). Herders observations about earlier snowmelt agree with the meteorological records (Lépy and Pasanen 2017; Rasmus, Kumpula, & Jylhä, 2014; Vikhamar-Schuler *et al.*, 2010).

Kivinen, Rasmus, Jylhä, and Laapas (2017) found that extremely cold weather events have significantly declined in all seasons during the past 100 years and extremely warm weather events increased particularly in spring and autumn. Vikhamar-Schuler *et al.* (2016) concentrated on exceptionally warm winter periods during the past century, often associated with rainfall and subsequent ground ice formation. These warm events have been frequent during 2000s, increasing in frequency during the study period.

Implications of changes in winter weather for reindeer husbandry

The general consensus among interviewed herders was that the changes in the quality of pastures, particularly decreased access to forage and the amount of forage, have increased the number of working hours and altered herding practices (Table 3). Changes in snow conditions have negatively affected access to forage such that herding has become more difficult overall as a result (Table 3). There is a sense that pastures are becoming

“locked” more often, meaning conditions which prevent reindeer reaching forage beneath the snow (*heajos guohtun*). “Locking” can be caused by (i) icing of the ground layer, which results from rain followed by freezing temperatures before there is adequate snow cover, or if the snow cover has melted completely during the winter; (ii) ice layers (*geardni*), which are caused by winter rain-on-snow or thaw events followed by freezing temperatures (one herder said that three discrete ice layers could effectively “lock” the pastures (GG3)); and (iii) snow drifts resulting from high snowfall in late winter, increased winds and high density of birch stems (Table 3). Two reindeer herders noted, “When there are more [shrub and mountain] birch, there will be more snow drifts” (GG1, GG2). Enhanced formation of snow drifts means that access to ground lichens can locally decrease, even if lichen cover remains undiminished.

Another finding reported by herders concerns the amount and consistency of snow. Animals keep busy and remain in one place when digging for forage below the snow (*fieski*). Adequate snow depth is needed for this, and as the timing of a complete snow cover has more frequently been delayed until late autumn, conditions for *fieski* tend to occur later than previously (GG2). One result is that herders are forced to manage their reindeer more intensively (GG2) (Table 3). When a complete snow cover was present earlier, the winter flocks used to be tamer and easier to handle since reindeer tended not to move outside of the *fieski* zone but turned

Table 3. The effects of climate change during the year on the quality of the pastures and working conditions of herders as revealed by the interviews

Herders' observations	PASTURE QUALITY		WORKING HOURS		
	Amount of forage	Access to forage	Feeding	Herding	Making fences
More snow drifts		↓		↑	
More ice-crusts snow layers		↓	↑	↑	
More frequent icing of ground		↓	↑	↑	
Thin or non-existing early winter snow cover			↓	↑	↑
Deep late winter snow cover		↓	↑	↑	
Earlier snow melt		↑(†)	↓		
Decrease in lichen cover	↓		↑		
Increase in birch	↓ (†)	↓			
Increase in oceanic plant species	↓ (†)				

↑ increasing effect, ↓ reducing effect, (†) increasing effect on summer forage.

back by themselves. Now herders have to make temporary enclosures to keep reindeer within the designated areas (Table 3). At the same time, the aforementioned icing of the ground requires more effort, as herders need to move animals to unaffected areas or furnish animals with supplemental forage.

Interviewed herders have noted that the prolonged snow-free periods in both spring and fall have improved the availability of forage for reindeer and contributed to good condition of reindeer. *"Snow melts here [in Gáregasnjárga] normally during Mother's Day (11st May), but in the 2000's it has not been the case, snow has melted earlier, but it has then snowed sometimes afterwards. Early snowmelt, mild weather and early start of the grass growth would be ideal for reindeer, it does not matter if it was cold in early summer, so long as snow melted, ponds of the mires dried, no insects developed"* (G).

The effects of snow conditions reported by herders are congruent with scientific studies on this subject. Research has shown that deep or icy snow or late snow melt may lead to high winter mortality of reindeer as well as to low calf survival during the following spring (Helle & Kojola, 2008; Kumpula & Colpaert, 2003; Lee, Press, Lee, Ingold, & Kurttila, 2000). Especially, detrimental is the formation of ice on pastures if supplementary winter feeding of reindeer is not in use (Rasmus, Kivinen, & Irannezhad, 2018; Riseth et al., 2011; Turunen et al., 2016). The prevalence and frequency of ground ice formation events have rarely been studied within the research area, although Eira (2012) and Rasmus et al. (2018) have reported increased frequency of *goavvi* events or extensive basal ice formation.

Changes in vegetation and effects of herbivory on reindeer pastures

Changes in vegetation cover

Herders reported changes in vegetation cover, for example, an increase in the abundance of mountain birch; birch grows faster and at higher elevations than previously (GG1, GG2). This has been observed particularly in coastal areas, but also further inland (Table 4). Willow does not spread as quickly as birch, but it is still expanding by increasing rapidly in height and cover (GG1). Herders generally felt that graminoids had become more

abundant than before (Table 4). According to one herder, there are more mushrooms now than before, *"reindeer are behaving crazier about them than in the past"* (GG2).

At certain places within valleys, the mountain birch forest has become so dense that it is not possible for reindeer to utilise the areas (GG2). Within inland lichen heaths, the increase in birch forests and certain vascular understorey plants affect reindeer husbandry and pasture quality negatively by reducing the amount of ground lichen cover. One mechanism is that the dense cover of fallen leaves in autumn within relatively closed forest canopies suppresses the growth of ground lichens. A positive effect of the increase in the birch forest is that the availability of fresh green forage in early summer during the lactation period is improved for the reindeer and their newly born calves.

Herders' observations of decrease in lichens while birch and some graminoids (*Deschampsia cespitosa*, *D. flexuosa*) increase are consistent with research (Myers-Smith et al., 2011; Walker et al., 2006). Satellite imagery from the Guovdageaidnu and Kárášjohka areas (Tømmervik et al., 2004) parallels herders' observations on increases in the abundance of mountain birch. Abundance and height of woody plants are also increasing in other Arctic regions (Käyhkö & Horstkotte 2017; Myers-Smith et al., 2011; Normand et al., 2017; Tape et al., 2006).

Climate variability and change affect the growth conditions for mountain birch forests: temperature, precipitation and atmospheric nitrogen (Tømmervik et al., 2004). In recent decades, both forest and understorey vegetation of Finnmark have developed in ways that reflect more oceanic conditions. For example, lichens have decreased and according to Tømmervik et al. (2004) one reason for this is that lichens grow slowly and some vascular plant species (like *Cornus suecica*, *Vaccinium myrtillus*) are better competitors under moist conditions. The documented increase in precipitation in the Finnmark area during the last century (Vikhamar-Schuler et al., 2010) is believed to be favourable for seed germination and growth of birch near the tree line (Kullman, 2002; Wielgolaski, 2002). Research on the abundance of mushrooms is scarce. Some results suggest that belowground fungal communities could be controlled by herbivory, and moth outbreaks could have a cascading effect on root-associated fungi (Saravesi et al., 2015).

Table 4. Comparison of herders' knowledge and scientific knowledge concerning the changes in the vegetation cover in the research area

Herders' observations	Scientific knowledge	Reference
Increase in birch (GG)	Increased birch growth favoured by prolonged growing season and increased precipitation. Establishment of birch facilitated by reindeer.	Tømmervik <i>et al.</i> (2004)** Vikhamar-Schuler <i>et al.</i> (2010)** Helle (2001)* Wielgolaski (2002)* Lempa <i>et al.</i> (2005)* Tømmervik <i>et al.</i> (2009)**
Increase in shrubs (GG)	Increase in shrub cover due to climate warming	Kullman (2002)* den Herder <i>et al.</i> (2004)*
Increase in graminoids (G, GG)	Increased graminoids as a result of moth outbreaks in defoliated forests. Increase in graminoids due to warming. Graminoids benefit from the significant grazing pressure.	Lempa <i>et al.</i> (2005)* Walker <i>et al.</i> (2006)* Bråthen and Oksanen (2001)* Eskelinen and Oksanen (2006)*
Increase in vascular plants (GG)	Warmer and moister conditions favour vascular plants.	Tømmervik <i>et al.</i> (2004)**
Decrease in lichen cover (G, GG)	Lichen cover decreased due to reindeer grazing and trampling. Lichen cover declined during 1961–2000. Lichen cover decreased due to warming. Lichen decrease due to increase in vascular plants.	Moen and Danell (2003)* Lempa <i>et al.</i> (2005)* Bråthen <i>et al.</i> (2007)** Tømmervik <i>et al.</i> (2009)** Cohen <i>et al.</i> (2013)** Reinert and Benjaminsen (2015)* Tømmervik <i>et al.</i> (2004)** Walker <i>et al.</i> (2006)* Virtanen (2000)*
Decrease in arboreal lichen (G)	No data	See references on decrease in birch.
Decrease in birch: moth outbreaks and concurrent defoliation of birch forest more common (G, GG, M)	Reindeer has inhibited regeneration of forest by grazing and trampling. Background herbivory ¹ increases due to warmer and moister conditions. Rise in winter minimum temperatures favours moth outbreaks. Range expansion of autumnal moth and winter moth.	Kallio and Lehtonen (1973)** Lehtonen (1987)** Lehtonen and Heikkinen (1995)** Tenow <i>et al.</i> (2005)* Moen and Danell (2003)* Lempa <i>et al.</i> (2005)* Bråthen <i>et al.</i> (2007)** Biuw <i>et al.</i> (2014)* Helander-Renvall (2014)* Barrio <i>et al.</i> (2017)* Jepsen <i>et al.</i> (2008)* Jepsen <i>et al.</i> (2008)* Klemola <i>et al.</i> (2016)*

¹Chronic, low-intensity leaf damage by defoliating, mining and gall-forming invertebrates such as sawflies (*Hymenoptera: Tenthredinidae*).

References to scientific literature have been sorted according to the local relevance, ** meaning high relevance (studies conducted in the same locations than our interviews) and * meaning some relevance (studies conducted in the northern Fennoscandian mountain birch region).

Changes in vegetation caused by moth outbreaks

Despite herders' observation about more abundant mountain birch within wooded areas, the effects of mass outbreaks of moths can overshadow this trend locally. Herders had noticed that there have been moth outbreaks more often than earlier (Table 4). This has had significant effects on the use of mountain birch forests as reindeer pastures. In areas affected by extensive outbreaks in Gáregasnjárga, herders observed that the vegetation composition and cover have changed, with important implications for reindeer husbandry. Defoliation and mortality of birch trees have impacts not only on the availability of winter forage, but also on the availability of summer forage. As one of the herders said: “*Defoliation of birch forests by moth is significant for our [summer pasture] areas in Ohcejohka municipality and northern parts of Anár. . . . one just cannot understand it . . . the summer of 2008 was saved for example because there was plenty of mushrooms, so that it was not possible to see the effect of birch defoliation*

by moths on calf slaughter weights [in autumn], it saved the calves, because there was so many mushrooms, it was a good time for reindeer” (G). Ohcejohka and Gáregasnjárga herders reported that both ground and arboreal lichens and birch have decreased and the abundance of graminoids has increased. They largely link these changes to the large autumnal moth outbreak in the 1960s, which affected upland mountain birch forest and fell areas. For reindeer husbandry, the net result was that winter pasture quality has declined because lichens constitute important winter forage (Table 3). The negative effects for reindeer husbandry are increased expenses and working hours because animals require more frequent movements in search of lichens and require costly supplemental feeding. A potential positive effect of the decrease in mountain birch forest is that when the areas have become treeless, there is less snow cover than earlier and the area can be used longer in late winter. Currently, these areas can serve as calving grounds (G).

Herders in Gáregasnjárga state that due to attacks by autumnal moths, most old birch trees died; in some areas, nearly all trees have disappeared and the ground vegetation cover has changed. “Defoliated forests are still visible, in 1968 from Gáregasnjárga to Inari for over 10–15 km, there used to be a birch forest, then green larvae came, there were 2–3 larvae on each leaf. There used to be a lichen pasture, a couple of years after autumnal moth came, grass started to grow, wavy hairgrass, which killed the lichen, reindeer were fat due to grass which grew there for several years, when grass was finished, mosses came, soil became nutrient-poor, trees were decayed...” (G). In Guovdageaidnu and Máze, there have not been severe autumnal moth attacks, though in recent years moth damages have increased (GG, M). Herders reported outbreaks of winter moth during the 2000s in these areas; even the leaves of cloudberry were eaten by moths in summer 2008 (GG2).

The greatest change is the increased amount of graminoids and a decrease in ground lichens, in particular fruticose forms (Table 4). This has had a clear effect on the forage quality of winter pastures. In the herders’ words, “Grasses destroyed the pastures” (G). One of the herders (G6) noted that the quality of pastures has decreased because the amount of star-tipped reindeer lichen (*Cladina stellaris*) has declined. Herders claim that the forage value of winter pastures has declined because lichens, which form the basis of the winter diet of reindeer, have decreased though animals also consume some graminoids and shrubs in winter. Herders say that the decline in old birch trees means that arboreal lichens growing on the stems have also disappeared (Table 4). In earlier times, during late winter after the snow cover had hardened, reindeer would walk from tree to tree feeding on arboreal lichens, when available. Regeneration of the birch forest has been spatially variable in the Gáregasnjárga area. According to herders, forests have not recovered from previous autumnal moth outbreaks in fell areas, although at lower elevations there has been noticeable regeneration.

Scientific knowledge parallels herders’ observations that autumnal moth has a clear effect on birch forests and tree line. Severe outbreaks are known to have a long-term influence on mountain birch ecosystems (Tenow, Bylund, Nilsen, & Karlsson, 2005). Herders in Gáregasnjárga and the scientific literature have both linked the loss of birch forest to major outbreaks of the autumnal moth, which in 1965–66 defoliated about 60% (1350 km²) of forested area in the vicinity of the community (Tenow et al., 2005). Herders’ observation that more birches died in fell areas than in the lowlands is congruent with research done in Ohcejohka commune (Lehtonen, 1987). Especially in the vicinity of Geavvu (Kevo), birch grew very slowly and the area has long ago become treeless (Kallio & Lehtonen, 1973). Regeneration has been unsuccessful partly due to root rot that developed in the aftermath of the moth outbreak (Lehtonen & Heikkinen, 1995). Extensive autumnal moth damage had not been reported in the scientific literature in the Guovdageaidnu–Máze areas. However, during the years 2002–2008, outbreaks of autumnal and winter moths have been reported. The latest moth outbreak causing significant damage in the area was caused by winter moth during years 2006–2008. The rise in winter minimum temperatures is assumed to favour moth outbreaks, and warming facilitates the range expansion of autumnal and winter moth (Helander-Renvall, 2014; Jepsen et al., 2008; Klemola et al., 2016). In addition to moth outbreaks, foraging by small mammals like Norwegian lemmings (*Lemmus lemmus*) and grey-sided voles (*Clethrionomys rufocanus*), and background herbivory by invertebrates have been shown to be significant factors in tundra ecosystems (Barrio et al., 2017; Olofsson, Hulme, Oksanen, & Suominen, 2004).

Damages due to the low-intensity but widespread herbivory are assumed to grow with increasing temperature and precipitation (Barrio et al., 2017).

Changes in vegetation caused by reindeer grazing

Herders in both Gáregasnjárga and Máze were certain that reindeer herbivory does not harm healthy birch forest but, rather, stimulates growth. One herder summarised this as follows, “Birch need reindeer. We have had reindeer here for so long so that if the animals would harm birch, we would not have birch here” (G3). According to herders, reindeer do not browse all the leaves but carefully select some; these are assumed to be of highest quality. Therefore, reindeer keep old forests “clean”. Dense woodlands are not perceived as good pastures because reindeer cannot access the forest and there are no ground lichens growing there due to low light conditions. In late winter, reindeer graze moderately intensively on lichens growing on birch stems. Herders claim this does not have any effect on birch. According to some informants (M11, M12), moose are more destructive for birch because it browses bark to the extent that the stem becomes wounded.

Herders have observed that intensive grazing and trampling by reindeer prevent birch seedling growth and regeneration of forests in summer pastures, including those affected by moth herbivory (Table 4). Herders in Gáregasnjárga say that young and damaged forests (e.g. autumnal moth) do not tolerate as much grazing as mature ones. One informant said that “reindeer can prevent the growth of the seedlings” (G2) in the areas with large numbers of animals, for example, inside the enclosure or on an island. Via grazing and trampling, reindeer might destroy some shoots as well (M11). According to herders, another way reindeer may have a negative effect on birch is that in autumn animals rub their antlers against saplings and in doing so can mortally wound them. In addition to root rot that developed in the aftermath of the moth outbreak, the consensus among herders is that reindeer themselves inhibit the regeneration of birch forests. Some contend that damages could have been prevented: “All the adult birch should have been cut when the moon is growing (when evaporation is strongest), then the shoots would have grown back. Now the birch died along the roots” (G7). Herders also had a concrete suggestion for renewal of the area: “Defoliated areas should be left in peace even for a couple of years, so that seedlings could be growing in peace” (G).

As a key reason for the long-term loss of lichens, at least in Gáregasnjárga, herders see soil erosion related to the retreating forest due to moth outbreaks. One informant said: “Earlier birch protected the earth; now wind and water erode the soil” (G4). Nevertheless, some herders said that the large number of generally unsupervised reindeer in the 1980s also had an effect on the decrease in ground lichen. Reindeer were both from Finland and Norway, as the fence between Norway and Finland was not complete (G). In the vicinity of Gáregasnjárga, there is also a certain amount of overlap in the territories where reindeer graze and trample year-round.

Based on scientific knowledge, healthy mountain birch forests tolerate moderate grazing and may benefit from it and grow faster (Helle, 2001). Reindeer grazing can also facilitate the establishment of birch because trampling creates gaps in the vegetation for seedlings to grow on the fell areas, thus affecting the growth of birch up to 300 m in elevation (Lempa, Neuvonen, & Tømmervik, 2005; Tømmervik et al., 2009; Wielgolaski, 2002). However, strong grazing and trampling pressure are known to negatively affect the birch forests, and death of seedlings is a

common phenomenon in intensively grazed birch forests (Helle, Kajala, Niva, & Särkelä, 1998; den Herder, Kytöviita, & Niemelä, 2003; Lehtonen and Heikkinen 1995). Herders' observations agree with the scientific literature that damaged (autumnal moth) or limited areas (enclosures, islands) affected by heavy grazing and trampling regenerate very slowly if grazing is continuous (Vuojala-Magga & Turunen, 2015). Herders stated that regeneration of mountain birch forests has not succeeded near Gáregasnjárga because reindeer trample the areas and eat seedlings. This is in agreement with many published scientific studies (Biuw *et al.*, 2014; Bråthen *et al.*, 2007; Kallio & Lehtonen, 1973; Lehtonen & Heikkinen, 1995; Moen & Danell, 2003; Tenow *et al.*, 2005). Reindeer browsing has also been shown to be an important mortality factor for saplings in mountain birch forests defoliated by the outbreaks (Lehtonen & Heikkinen 1995).

The decrease in lichens in places where graminoids increase has been both observed by herders and also reported in the scientific literature (Table 4), but the explanations differ somewhat. There is agreement within the scientific literature that high reindeer density has negative effects on lichen cover. A decrease in lichen biomass due to reindeer grazing has been shown in several studies (Bråthen *et al.*, 2007; Lempa *et al.*, 2005; Moen & Danell, 2003; Reinert & Benjaminsen, 2015), and significant grazing pressure seems to also benefit graminoids to the detriment of lichens (Bråthen & Oksanen, 2001; Eskelinen & Oksanen, 2006). Especially, detrimental is year-round grazing with no pasture rotation, as dry lichens are easily crushed and the shattered fragments are susceptible to wind and water erosion (Forbes & Kumpula, 2009; Kumpula, Kurkilahti, Helle, & Colpaert, 2014; Kumpula, Stark, & Holand, 2011). In some experiments, increases in vascular plant biomass due to decreased reindeer grazing have caused lichen biomass to decrease (Virtanen, 2000). After grazing pressure has decreased, regeneration of lichen pastures can be relatively rapid (Pajunen, Virtanen, & Roininen, 2008; Tømmervik, Bjerke, Gaare, Johansen, & Thannheiser, 2012).

Discussion

All of the interviewed herders had observed that both the canopy and understorey of mountain birch forests in Guovdageaidnu-Máze and Gáregasnjárga areas have changed during the past 50 years. The changes in weather conditions and vegetation have significantly affected reindeer husbandry by transforming herding practices and increasing expenses.

Even though we do not aim at validation of either of the two “ways of knowing” presented here, such general comparisons enrich our understanding of recent changes and clarifies the useful features of the respective knowledge systems. The knowledge of herders concerning Nordic mountain birch forest dynamics in large part coincides with the existing scientific knowledge base. Active and retired herders possess practitioners' knowledge that is clearly grounded in, and related to, specific events and processes. This extends back several decades, so within the lifespan of retired herders. Yet knowledge pertaining to extreme events may also be handed down for several generations (Forbes *et al.*, 2016; Huntington *et al.*, 2004). There were also interesting inconsistencies between the knowledge systems, as well as knowledge gaps. Scientific and practitioners' knowledge may have relevance at different temporal or spatial scales. In climate research, the most common temporal depth is approximately 30 years, whereas ecological research (apart from long-term ecological monitoring) often concentrates on certain short periods (e.g. part of the growing

season) within a long continuum. Quantitative measurements are often spatially limited, especially in sparsely populated areas. They may also be seasonally biased. Herders' memories, on the other hand, may emphasise recent and extreme conditions, and to seasons and phenomena which are most relevant to reindeer herding. Emphasis on extreme events, and paying most attention to variables and changes which are most relevant to herding, such as “locked” winter pastures, are very useful for understanding what adaptive strategies have been deployed in different times and places and how they may be deployed in the future as the Arctic climate most likely continues to warm (Forbes *et al.*, 2016; IPCC, 2019). It has been suggested that public debate, for example, on climate change impacts may influence herders' perceptions on this topic. However, according to a global analysis by Marin and Berkes (2013), herders, hunters and fishers are well aware of the mainstream public climate change narrative, yet the media discourse does not override the knowledge gained through practice and direct experience.

Some phenomena observed by herders have not been reported within the scientific literature. These include, for example, changes in abundances of mushrooms. Beyond our study, the increase in weather variability has been reported by several northern or Arctic communities (ACIA, 2004; Huntington *et al.*, 2004; Krupnik and Jolly 2002; Meredith *et al.*, 2019). Scientific knowledge on the subject is scarce, regarding our research area, and results can be contradictory, partly due to incomplete understanding of the scales involved and measures of variability (e.g. Fischer and Knutti, 2014). In our interpretation, our informants were most often considering the rapid, intermittent changes in daily weather. In meteorological terms, this would mean a perceived decrease in weather persistence from one day to the next. To our knowledge, weather persistence of sub-Arctic Fennoscandia has not been explicitly studied.

On the other hand, not all processes or events reported by scientists were mentioned by our informants. The combined effects of herbivory and climate change on northern ecosystems have been recently studied (Biuw *et al.*, 2014; Cairns & Moen, 2004; den Herder *et al.*, 2004; Vowles, Lovehø, Molau, & Björk, 2017), as well as combined effects of historical human activities and climate change (Normand *et al.*, 2017) and potential feedbacks of herbivory on climate. Examples of these feedbacks include the reduction in deciduous shrub cover and height (cf. Kitti *et al.*, 2009; Kolari *et al.*, 2019), and the loss of fruticose lichen (Forbes & Kumpula, 2009; Helle & Jaakkola, 2008; Kumpula *et al.*, 2014). The former increases albedo, especially during the snow-covered period, meaning decreased absorption of heat at the ground level or snow cover surface (stabilising feedback); the latter decreases albedo during the snow-free period, resulting in increased absorption of heat (reinforcing feedback) (Cohen *et al.*, 2013; Olofsson *et al.*, 2009). Although important, our analysis does not encompass these complex issues as they did not explicitly stand out from our interview material. In previous studies, the effect of summer temperature and insect harassment during hot summers on reindeer condition and reindeer husbandry has been seen as significant (e.g. Weladji, Holand, & Almøy, 2003). This did not appear as a central theme in our interviews.

Another example of contrasting views arose in the discussion of lichen pasture deterioration, erosion and potential overgrazing by reindeer herds. Herders openly acknowledge the keystone role of reindeer, especially regarding how heavy trampling and grazing of seedlings impeded regeneration of mountain birch forests following massive moth outbreaks. The role of herbivorous moths

is nevertheless seen as highly significant in terms of triggering a sequence of events in the transition from mountain birch forest to treeless tundra, and the well-documented retreat of the forest after massive moth outbreaks is considered to be the overriding driver in this transition. In the scientific literature, and in the media (Ruukki 2016), reindeer trampling is often seen as a main explanatory factor of erosion (e.g. Uhlig & Zink 2006; Helle & Jaakkola 2008).

The scientific observations reviewed had varying relevance across scales (Tables 2 and 4). Most of the scientific literature on weather changes (Table 2) had high local relevance (conducted in the same locations as our interviews) and coincided with local practitioners' knowledge. Scientific knowledge on changes in the vegetation cover (Table 4) is, in some cases, based on literature with lower local relevance (conducted in the northern Fennoscandian mountain birch region, but not in the same locations as our interviews). This was the case with research on increases in shrubs and graminoids. Several studies concentrating on decreases in lichen cover and increases in birch and vascular plants had high local relevance. In addition, literature on decreases in mountain birch due to moth outbreaks and inhibited regeneration due to reindeer grazing included several locally relevant studies.

Our results confirm the conclusions of recent studies in which local or practitioners' knowledge on northern ecosystems have been related with scientific findings (e.g. Riseth et al., 2011; Eira et al., 2013; Helander-Renvall, 2014; Horstkotte et al., 2017).

There is a need to better understand and relate herders' knowledge of past and ongoing changes with scientific studies in order to more sustainably manage reindeer rangelands in the contemporary milieu of multiple users (Bernes et al., 2015; Horstkotte et al., 2017). As national and international research funding calls and Arctic strategies demand more inclusive stakeholder involvement (European Commission, 2016; Prime Minister's Office, 2013), it is critical to see where scientific and practitioners' knowledge both converge and diverge, so that future research and decision-making can better incorporate different "ways of knowing" (*sensu* Kendrick, 2003). Especially, important is that practitioners can put observed events and processes into a locally relevant perspective, and enrich the meteorological and ecological data with aspects like experiences, impacts and coping. Also, local herding practices leading to measurable outcomes (e.g. vegetation changes, cf. Cohen et al., 2013; Horstkotte et al., 2017; Kolari et al., 2019) can be afforded their proper social-ecological context. Practitioners' view can also bring forth new research questions.

The herders interviewed have applied their knowledge to comprehend remarkably detailed patterns of pasture extent, conditions and forage dynamics in space and time. Reindeer husbandry has functioned within the region for centuries, while simultaneously altering mountain birch forests (Horstkotte et al., 2017). The determining role of scientific knowledge in the management regime of reindeer herds of our research area has still been indisputable during the past decades (Hukkinen et al., 2006), as has been the low local decision-making power (Heikkinen et al., 2012; Sarkki et al., 2018). Herders have seldom been seen as "local managers", making the actual management decisions based on their practitioners' knowledge.

An example of the very recent emphasis on participation, and approaches that connect science, policy and society, is the process of setting the maximum reindeer numbers in Finland. Reindeer management in Finland belongs under the jurisdiction of the Ministry of Agriculture and Forestry (MAF). Every 10 years,

MAF sets the maximum number of reindeer for each herding district. Already 30 years ago (MAF, 1989), it was suggested to allow more decision-making power to herding districts. However, maximum numbers have continuously been set according to the ecological carrying capacity of winter pastures, as estimated by the state-funded and mandated processes aimed at minimising conflicts with forestry and agriculture (MAF, 1989, 1999). The most recent process, setting the maximum numbers for the period of 2020–2030, generally succeeded in involving several stakeholders, including local herding communities, and recommendations were at least partly based both on the scientific and practitioners' knowledge (MAF, 2019). It is noteworthy that researchers involved in the process considered co-planning and local participation as central methods in the northern land use management (Kumpula et al., 2019a, 2019b).

Reindeer husbandry shares the same operational space with several other land users in northern Fennoscandia, encompassing the Sápmi region. Intensifying land use such as forestry, mining industry and tourism has contributed to decrease, fragmentation and degradation of the pastures (Kumpula et al., 2014; Pape & Löffler, 2012). Unlike in North America, where Arctic indigenous people have a legal right to participate in the co-management of living resources, access to reindeer rangelands in Sápmi depends on usufruct rights (Forbes and Stammer, 2009). Decades of top-down reindeer management have led to distrust of governance institutions (Forbes et al., 2006). A central question in future land use planning is how different actors can use the natural resources without significantly degrading the resources and reducing the range of options for use by others. Co-production of knowledge where both scientific findings and local information are combined facilitates the incorporation of qualitative aspects into the discussion (Markkula, Turunen, & Kantola, 2019). It provides locally valid information concerning how to prepare for the future (Huntington et al., 2004; UNESCO, 2017) and facilitates integrated understanding needed in land use planning processes (Horstkotte et al., 2017; Raymond et al., 2010; Sandström et al., 2003).

All knowledge systems involved need to participate in a mutually respectful dialogue to determine which approach is the most desirable, and to what outcome. True integration in fact is the crux of the interactions among knowledge systems (cf. Gratani et al., 2011). As the *de facto* practitioners of reindeer management over generations in the mountain birch forest and adjoining fell tundra zones, a meaningful role for Saami reindeer herders would be justifiable in the process. Viable reindeer rangelands should meet not only the biological needs of the reindeer itself, but also suit the herders' sociocultural imperatives, such as passing on their particular ways of knowing in variable geographical and social-ecological contexts, to the next generation (Forbes et al., 2006; Laakso 2008; Ostrom, 2011).

Conclusions

Our results show that through a participatory research approach a rich body of knowledge can be assembled, and that the different knowledge systems, or "ways of knowing", can coalesce from distinct yet complementary bases. It is nevertheless anticipated that further integration of these knowledge systems and better protocols for co-production of knowledge are critically needed in the near future. Learning on "how to relate knowledge from different systems for the purpose of improved decisions and solutions" is called for by IPCC (2019), as well.

This study has demonstrated that reindeer herders have relevant and practical knowledge of the present state and recent historic changes of the mountain birch forest ecosystem in northern Fennoscandia. In northern Canada and Alaska, the value of practitioners' knowledge has been recognised legally through land claims and has become progressively integrated into research and administration (Forbes & Stammler 2009). At present, ecosystem management of Fennoscandia is based primarily on scientific knowledge when it comes to state administrative and regulatory regimes. Practitioners' knowledge does not have the same status and has not been properly accounted for in laws and regulations. As such, the acceptance of practitioners' knowledge is generally much more contested and conflicted in the policy arena, than as an academic inevitability (cf. Sara 2011; Turi and Keskitalo 2014; Benjaminsen, Reinert, Sjaastad, & Sara, 2015). We conclude that better integration of practitioners' knowledge with scientific knowledge will improve critical understanding of cultural land use patterns, cultural adaptation to local ecosystems and sustainable development of local communities where reindeer husbandry remains an important livelihood.

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References

- ACIA. (2004). *Impacts of a Warming Arctic: Arctic Climate Impact Assessment (ACIA) overview report*. Cambridge: Cambridge University Press.
- Adenskögl, M. (2018). Democratic innovations in political systems—Towards a systemic approach. *Örebro Studies in Political Science*, 42.
- Agrawal, A. (1995). Dismantling the divide between indigenous and scientific knowledge. *Development and Change*, 26(3), 413–439.
- Aikio, M. S., & Müller-Wille, L. (2002). Living at the timberline: The Sámi and the mountain birch forests in northernmost Europe. In S. Kankaanpää, L. Müller-Wille, P. Susiluoto, & M.-L. Sutinen (Eds.), *Northern Timberline Forests: Environmental and Socio-economic Issues and Concerns* (pp. 40–56). Jyväskylä: Finnish Forest Research Institute.
- Alexander, C., Bynum, N., Johnson, E., King, U., Mustonen, T., Neofotis, P., ... Weeks, B. (2011). Linking indigenous and scientific knowledge of climate change. *BioScience*, 61(6), 477–484.
- Anschlag, K., Broll, G., & Holtmeier, F.-K. (2008). Mountain birch seedlings in the treeline ecotone, subarctic Finland: Variation in above- and below-ground growth depending on microtopography. *Arctic, Antarctic, and Alpine Research*, 40, 609–616.
- Armitage, D., Berkes, F., Dale, A., Kocho-Schellenberg, E., & Patton, E. (2011). Co-management and the co-production of knowledge: Learning to adapt in Canada's Arctic. *Global Environmental Change*, 21, 995–1004. doi: 10.1016/j.gloenvcha.2011.04.006
- Barrio, I., Lindén, E., Te Beest, M., Olofsson, J., Rocha, A., Soininen, E., ... Kozlov, M. (2017). Background invertebrate herbivory on dwarf birch (*Betula glandulosa-nana* complex) increases with temperature and precipitation across the tundra biome. *Polar Biology*, 40(11), 2265–2278. doi: 10.1007/s00300-017-2139-7
- Benjaminsen, T. A., Reinert, H., Sjaastad, E., & Sara, M. N. (2015). Misreading the Arctic landscape: A political ecology of reindeer, carrying capacities, and overstocking in Finnmark, Norway. *Norsk Geografisk Tidsskrift-Norwegian Journal of Geography*, 69(4), 219–229.
- Berkes, F. (2008). *Sacred Ecology*. New York: Routledge.
- Bernes, C., Bråthen, K., Forbes, B., Speed, J., & Moen, J. (2015). What are the impacts of reindeer/caribou (*Rangifer Tarandus* L.) on arctic and alpine vegetation? A systematic review. *Environmental Evidence*, 4(1), 1–26.
- Biuw, M., Jepsen, J., Cohen, J., Ahonen, S., Tejesvi, M., Aikio, S., ... Ims, R. A. (2014). Long-term impacts of contrasting management of large ungulates in the arctic tundra-forest ecotone: Ecosystem structure and climate feedback. *Ecosystems*, 17, 890–905.
- Bråthen, K. A., Ims, R., Yoccoz, N., Fauchald, P., Tveraa, T., & Hausner, V. (2007). Induced shift in ecosystem productivity? Extensive scale effects of abundant large herbivores. *Ecosystems*, 10(5), 773–89.
- Bråthen, K. A., & Oksanen, J. (2001). Reindeer reduce biomass of preferred plant species. *Journal of Vegetation Science*, 12(4), 473–480.
- Cairns, D. M., Lafon, C., Moen, J., & Young, A. (2007). Influences of animal activity on treeline position and pattern: implications for treeline responses to climate change. *Physical Geography*, 28, 419–433.
- Cairns, D. M., & Moen, J. (2004). Herbivory influences tree lines. *Journal of Ecology*, 92, 1019–1024.
- Cohen, J., Pulliainen, J., Ménard, C.B., Johansen, B., Oksanen, L., Luojus, K., & Ikonen, J. (2013). Effect of reindeer grazing on snowmelt, albedo and energy balance based on satellite data analyses. *Remote Sensing of Environment*, 135, 107–117.
- Crate S. A., Forbes, B. C., King, L., & Kruse, J. (2010). Contact with nature. In J. N. Larsen, P. Schweitzer, & G. Fondahl (Eds.), *Arctic Social Indicators: A Follow-up to the Arctic Human Development Report (TemaNord 519)* (pp. 109–127). Copenhagen: Nordic Council of Ministers.
- den Herder, M., Kytöviita, M.-M., & Niemelä, P. (2003). Growth of reindeer lichens and effects of reindeer grazing on ground cover vegetation in a Scots pine forest and a subarctic heathland in Finnish Lapland. *Ecography*, 26, 3–12.
- den Herder, M., Virtanen, R., & Roininen, H. (2004). Effects of reindeer browsing on tundra willow and its associated insect herbivores. *Journal of Applied Ecology*, 41, 870–879.
- Eira, I. M. G. (2012). The silent language of snow: Sámi traditional knowledge of snow in times of climate change. PhD dissertation. Tromsø: University of Tromsø.
- Eira, I. M. G., Jaedicke, C., Magga, O. H., Maynard, N. G., Vikhamar-Schuler, D., & Mathiesen, S. D. (2013). Traditional Sámi snow terminology and physical snow classification – Two ways of knowing. *Cold Regions Science and Technology*, 85, 117–130. doi: 10.1016/j.coldregions.2012.09.004
- Emanuelsson, U. (1987). Human influence on vegetation in the Torneträsk area during the last three centuries. *Ecological Bulletins*, 38, 95–111.
- Eskelinen, A., & Oksanen, J. (2006). Changes in the abundance, composition and species richness of mountain vegetation in relation to summer grazing by reindeer. *Journal of Vegetation Science*, 17(2), 245–254.
- European Commission. (2016). An integrated European Union policy for the Arctic. URL: https://eeas.europa.eu/arctic-policy/eu-arctic-policy_en (assessed 20 November 2019).
- FAO (Food and Agriculture Organization of United Nations). (2017). What is local knowledge? URL: <http://www.fao.org/docrep/007/y5610e/y5610e01.htm> (assessed 24 October 2018).
- Fischer, E., & Knutti, R. (2014). Impacts: Heated debate on cold weather. *Nature Climate Change*, 4, 537–538. doi: 10.1038/nclimate2286
- Forbes, B. C. (2006). The challenges of modernity for reindeer management in northernmost Europe. In B. C. Forbes, M. Bølter, L. Müller-Wille, J. Hukkinen, F. Müller, N. Gunslay, & Y. Konstantinov (Eds.), *Reindeer Management in Northernmost Europe: Linking Practical and Scientific*

- Knowledge in Social-ecological System (Ecological Studies 184)* (pp. 11–25). Berlin: Springer-Verlag.
- Forbes, B. C., Macias-Fauria, M., & Zetterberg, P. (2010). Russian Arctic warming and “greening” are closely tracked by tundra shrub willows. *Global Change Biology*, 16(5), 1542–1554.
- Forbes, B. C., & Kumpula, T. (2009). The ecological role and geography of reindeer (*Rangifer tarandus*) in northern Eurasia. *Geography Compass*, 3/4, 1356–1380.
- Forbes, B. C., Kumpula, T., Meschtyb, N., Laptander, R., Macias-Fauria, M., Zetterberg, P., ... Bartsch, A. (2016). Sea ice, rain-on-snow and tundra reindeer nomadism in Arctic Russia. *Biology Letters*, 12. doi: [10.1098/rsbl.2016.0466](https://doi.org/10.1098/rsbl.2016.0466)
- Forbes, B. C., & Stammer, F. (2009). Arctic climate change discourse: the contrasting politics of research agendas in the West and Russia. *Polar Research*, 28(1), 28–42.
- Forbes, B. C., Tolvanen, A., Wielgolaski, F. E., & Laine, K. (2005). Rates and processes of natural regeneration in disturbed habitats. In F. E. Wielgolaski (Ed.), *Plant Ecology, Herbivory and Human Impact in Nordic Mountain Birch Forests* (pp. 193–202). Berlin: Springer.
- Gratani, M., Butler, J. R., Royce, F., Valentine, P., Burrows, D., Canendo, W. I., & Anderson, A. S. (2011). Is validation of indigenous ecological knowledge a disrespectful process? A case study of traditional fishing poisons and invasive fish management from the Wet Tropics, Australia. *Ecology and Society*, 16(3).
- Heikkinen, H. I., Sarkki, S., & Nuttall, M. (2012). Users or producers of ecosystem services? A scenario exercise for integrating conservation and reindeer herding in northeast Finland. *Pastoralism*, 2(11).
- Helander-Renvall, E. (2014). Relationships between Sami reindeer herders, lands, and reindeer. In G. Marvin & S. McHugh (Eds.), *Routledge Handbook of Human-Animal Studies* (pp. 246–258). London and New York: Routledge.
- Helle, T. (2001). Mountain birch forests and reindeer husbandry. In F. E. Wielgolaski (Eds.), *Nordic Mountain Birch Ecosystems* (pp. 279–291). Paris and Parthenon, New York and London: UNESCO.
- Helle, T., & Jaakkola, L. M. (2008). Transitions in herd management of semi-domesticated reindeer in northern Finland. *Annales Zoologici Fennici*, 45(2), 81–101. doi: [10.5735/086.045.0201](https://doi.org/10.5735/086.045.0201)
- Helle T., Kajala, L., Niva, A., & Särkelä, M. (1998). Poron laidunnuksen vaikutus tunturikoivikoiden rakenteeseen (Effect of reindeer grazing on the structure of mountain birch forests). In M. Hyppönen, T. Penttilä, & H. Poikajärvi (Eds.), *Effect of Reindeer on Forest and Fell Environments (Finnish Forest Research Institute Research Papers 678)* (pp. 132–141). Helsinki: Finnish Forest Research Institute.
- Helle, T., & Kojola, I. (2008). Demographics in an alpine reindeer herd: effects of density and winter weather. *Ecography*, 31, 221–230. doi: [10.1111/j.2008.0906-7590.04912.x](https://doi.org/10.1111/j.2008.0906-7590.04912.x)
- Hofgaard, A. (1997). Inter-relationships between treeline position, species diversity, land use and climate change in central Scandes Mountains of Norway. *Global Ecology and Biogeography Letters*, 6, 419–429.
- Horstkotte, T., Utsi, T. A., Larsson-Blind, Å., Burgess, P., Johansen, B., Käyhkö, J., Oksanen, L. & Forbes, B. C. (2017). Human–animal agency in reindeer management: Sami herders’ perspectives on vegetation dynamics under climate change. *Ecosphere*, 8(9), e01931. doi: [10.1002/ecs2.1931](https://doi.org/10.1002/ecs2.1931)
- Hukkinen, J., Müller-Wille, L., Aikio, P., Heikkinen, H., Jääskö, O., Laakso, A., ... West, N. (2006). Development of participatory institutions for reindeer management in Finland: A diagnosis of deliberation, knowledge integration and sustainability. *Ecological Studies*, 184, 47–71.
- Huntington, H., Callaghan, T., Fox, S., & Krupnik, I. (2004). Matching traditional and scientific observations to detect environmental change: a discussion on Arctic terrestrial ecosystems. *Ambio Special Report*, 13, 18–23.
- Huntington, H. P., Carey, M., Apok, C., Forbes, B. C., Fox, S., Holm, L. K., ... Stammer, F. (2019). Climate change in context: putting people first in the Arctic. *Regional Environmental Change*, 19(4), 1217–1223. doi: [10.1007/s10113-019-01478-8](https://doi.org/10.1007/s10113-019-01478-8)
- IASSA (International Arctic Social Sciences Association). (1998). URL: <https://iassa.org/about-iassa/research-principles> (assessed 15 March 2018).
- Inga, B. (2007). Reindeer (*Rangifer tarandus tarandus*) feeding on lichens and mushrooms: traditional ecological knowledge among reindeer-herding Sami in northern Sweden. *Rangifer*, 27, 93–106.
- Ingold, T. (2000). *The Perception of the Environment: Essays in Livelihood, Dwelling and Skill*. London: Routledge.
- IPCC. (2019). Chapter 1: Framing and Context of the Report. In H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, M. Nicolai, A. Okem, J. Petzold, B. Rama, & N. Weyer (Eds.), *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*. In press.
- Itkonen, T. (1984 and 1948). *Suomen lappalaiset I-II (Lapps in Finland I-II)*. Porvoo: WSOY.
- Jäske, M. (2018). Participatory innovations and maxi-publics: The influence of participation possibilities on perceived legitimacy at the local level in Finland. *European Journal of Political Research*, 58(2), 603–630.
- Jepsen, J., Hagen, S., Ims, R., & Yoccoz, N. (2008). Climate change and outbreaks of the geometrids *Operophtera brumata* and *Epirrita autumnata* in subarctic birch forest: Evidence of a recent outbreak range expansion. *Journal of Animal Ecology*, 77(2), 257–264.
- Kallio, P., & Lehtonen, J. (1973). Birch forest damage caused by *Oporinia autumnata* (Bkh.) in 1965–66 in Ohcejohka, N Finland. *Reports of Kevo Subarctic Research Station*, 10, 55–69.
- Käyhkö, J., & Horstkotte, T. (Eds.). (2017). *Reindeer Husbandry under Global Change in the Tundra Region of Northern Fennoscandia*. Turku: Painosalama Oy.
- Kendrick, A. (2003). Caribou co-management in northern Canada: fostering multiple ways of knowing. In F. Berkes et al., (Ed.), *Navigating Social–Ecological Systems. Building Resilience for Complexity and Change*. Cambridge: Cambridge University Press.
- Kitti, H., Gunsley, N., & Forbes, B. C. (2006). Defining the quality of reindeer pastures: The perspectives of Sami reindeer herders. In B. C. Forbes, M. Bølter, L. Müller-Wille, J. Hukkinen, F. Müller, N. Gunsley, & Y. Konstantinov (Eds.), *Reindeer Management in Northernmost Europe: Linking Practical and Scientific Knowledge in Social-ecological Systems (Ecological Studies 184)*, (pp. 141–165). Berlin: Springer.
- Kitti, J. (2004). No new information about reindeer husbandry. *Lapin Kansa*, 30 August 2004, p. 5. (in Finnish)
- Kitti, H., Forbes, B. C., & Oksanen, J. (2009). Long- and short-term effects of reindeer grazing on tundra wetland vegetation. *Polar Biology*, 32, 253–261. doi: [10.1007/s00300-008-0526-9](https://doi.org/10.1007/s00300-008-0526-9)
- Kivinen, S., Rasmus, S., Jylhä, K., & Laapas, M. (2017). Climate variations over the past century (1914–2013) in Northern Fennoscandia: Trends and extreme events. *Climate*, 5(1), 16. doi: [10.3390/cli5010016](https://doi.org/10.3390/cli5010016)
- Klemola, T., Andersson, T., & Ruohomäki, K. (2016). No regulatory role for adult predation in cyclic population dynamics of the autumnal moth, *Epirrita autumnata*. *Ecological Entomology*, 41(5), 582–589.
- Kolari, T., Kumpula, T., Verdonen, M., Forbes, B. C., & Tahvanainen, T. (2019). Reindeer grazing controls willows with minor effects on plant communities in Fennoscandian oro-arctic mires. *Arctic, Antarctic, and Alpine Research*, 51, 506–520. doi: [10.1080/15230430.2019.1679940](https://doi.org/10.1080/15230430.2019.1679940)
- Krippendorff, K. (1980). *Content Analysis: An Introduction to its Methodology*. Beverly Hills, CA: Sage.
- Krupnik, I., & Jolly, D. (Eds.). (2002). *The Earth is Faster Now: Indigenous Observations of Arctic Environmental Change*. Fairbanks: ARCUS.
- Kullman, L. (2002). Rapid recent range-margin rise of tree and shrub species in the Swedish Scandes. *Journal of Ecology*, 90, 68–77.
- Kumpula, J., & Colpaert, A. (2003). Effects of weather and snow conditions on reproduction and survival of semi-domesticated reindeer (*R.t. tarandus*). *Polar Research*, 22(2), 225–233.
- Kumpula, J., Jokinen, M., Tauriainen, J., Pekkarinen, A.-J., Tahvonen, O., Stark, S., ... Oinonen, K. (2019b). Reindeer Herding Inventory and Sustainable Bioeconomy with Reindeer Pastures. Summary report, project KEBIPORO. Helsinki: LUKE, University of Helsinki, University of Lapland. (in Finnish)
- Kumpula J., Kurkilahti, M., Helle, T., & Colpaert, A. (2014). Both reindeer management and several other land use factors explain the reduction in

- ground lichens (*Cladonia* spp.) in pastures grazed by semi-domesticated reindeer in Finland. *Regional Environmental Change*, 14(2), 541–559.
- Kumpula, J., Siitari, J., Siitari, S., Kurkilahti, M., Heikkinen, J., & Oinonen, K. (2019a). Reindeer herding area winter pasture inventory 2016–2018: Changes in winter pasture status and reasons for changes. Natural Resources and Bioeconomy Research 33/2019. Helsinki: Natural Resources Center. 86 pp. (in Finnish)
- Kumpula, J., Stark, S., & Holand, Ø. (2011). Seasonal grazing effects by semi-domesticated reindeer on subarctic mountain birch forests. *Polar Biology*, 34, 441–453.
- Laakso, A. M. (2008). The shadow field of reindeer management: a case study from Finland. *Acta Borealia*, 25(2), 138–159. doi: [10.1080/08003830802496703](https://doi.org/10.1080/08003830802496703)
- Landbruksdepartementet. (2016). Ressursregnskapet for reindriftsnæringen 2015–2016 (Report of reindeer herding 2015–2016). Landbruksdepartementet Rapport 24/2016.
- Lee, S. E., Press, M. C., Lee, J. A., Ingold, T., & Kurttila, T. (2000). Regional effects of climate change on reindeer: A case study of the Muotkatunturi region in Finnish Lapland. *Polar Research*, 19, 99–105.
- Lehtola, V.-P. (2002). *The Sámi People. Traditions in Transition*. Inari: Kustannus-Puntsi.
- Lehtonen, J. (1987). Recovery and development of birch forests damaged by Epirrita autumnata in Ohcejohka area, north Finland. *Reports of Kevo Subarctic Research Station*, 20, 35–39.
- Lehtonen, J., & Heikkinen, R. K. (1995). On the recovery of mountain birch after *Epirrita* damage in Finnish Lapland, with a particular emphasis on reindeer grazing. *Écoscience*, 2, 349–356.
- Lempa, K., Neuvonen, S. & Tømmervik, H. (2005). Effects of reindeer grazing on pastures in a mountain birch system. In F. E. Wielgolaski (Ed.), *Plant Ecology, Herbivory and Human Impact in Nordic Mountain Birch Forests* (pp. 157–164). Berlin: Springer.
- Lépy, E., and Pasanen, L. (2017). Observed regional climate variability during the last 50 years in reindeer herding cooperatives of Finnish fell Lapland. *Climate*, 5(4), 81. doi: [10.3390/cli5040081](https://doi.org/10.3390/cli5040081)
- Macias-Fauria, M., Forbes, B. C., Zetterberg, P., & Kumpula, T. (2012). Eurasian Arctic greening reveals teleconnections and the potential for structurally novel ecosystems. *Nature Climate Change*, 2(8), 613–618.
- Magga, J. (2006). Reindeer herder lost in the jungle of science. In Forbes, B. C. (Ed.) et al., *Reindeer Management in Northernmost Europe: Linking Practical and Scientific Knowledge in Social-Ecological Systems*. Ecological Studies, Vol. 184, pp. 381–383. Berlin, Heidelberg: Springer.
- Marin, A., & Berkes, F. (2013). Local people's accounts of climate change: To what extent are they influenced by the media? *WIREs Climate Change*, 4, 1–8. doi: [10.1002/wcc.199](https://doi.org/10.1002/wcc.199)
- Markkula, I., Turunen, M. T., & Kantola, S. (2019). Traditional and local knowledge in land use planning: insights into the use of the Akwé: Kon Guidelines in Eanodat, Finnish Sápmi. *Ecology and Society*, 24(1), 20. doi: [10.5751/ES-10735-240120](https://doi.org/10.5751/ES-10735-240120)
- Meredith, M. et al. (Eds.) (2019). Chapter 3: Polar Regions. In H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, M. Nicolai, A. Okem, J. Petzold, B. Rama, & N. Weyer (Eds.), *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*. In press.
- Ministry of Agriculture and Forestry. (1989). Maximum number of reindeer winter stocks, proposal by the working group. MAF memorandum 1989. (in Finnish)
- Ministry of Agriculture and Forestry. (1999). Maximum number of reindeer winter stocks, proposal by the working group. MAF memorandum 1999:20. (in Finnish)
- Ministry of Agriculture and Forestry. (2019). Maximum number of reindeer winter stocks, proposal by the working group. MAF memorandum 2019. (in Finnish)
- Moen, J., Cairns, D. M., & Lafon, C. W. (2008). Factors structuring the treeline ecotone in Fennoscandia. *Plant Ecology and Diversity*, 1, 77–87.
- Moen, J., & Danell, Ö. (2003). Reindeer in the Swedish mountains: An assessment of grazing impacts. *Ambio*, 32(6), 397–402.
- Myers-Smith, I.H., Forbes, B. C., Wilmking, M., Hallinger, M., Lantz, T., Blok, D., ... Hik, D. S. (2011). Shrub expansion in tundra ecosystems: dynamics, impacts and research priorities. *Environmental Research Letters*, 6, 045509. doi: [10.1088/1748-9326/6/4/045509](https://doi.org/10.1088/1748-9326/6/4/045509)
- Neuvonen, S., Bylund, H., & Tømmervik, H. (2005). Forest defoliation risks in birch forests by insects under different climate and land use scenarios in northern Europe. In F. E. Wielgolaski (Ed.), *Plant Ecology, Herbivory and Human Impact in Nordic Mountain Birch Forests* (pp. 125–138). Berlin: Springer.
- Nieminen, M. (1994). *Poro – ruumiinrakenne ja elintoiminnat*. Rovaniemi: Riista- ja kalatalouden tutkimuslaitos.
- Nilsson, A. E., Carson, M., Cost, D.S., Forbes, B.C., Haavisto, R., Karlsdottir, A., ... Pelyasov, A. (2019). Towards improved participatory scenario methodologies in the Arctic. *Polar Geography*, doi: [10.1080/1088937X.2019.1648583](https://doi.org/10.1080/1088937X.2019.1648583)
- Normand, S., Høye, T., Forbes, B. C., Bowden, J., Davies, A., Odgaard, B., ... Wischniewski, J. (2017). Legacies of historical human activities in Arctic woody plant dynamics. *Annual Review of Environment and Resources*, 42, 541–567.
- Olofsson, J., Hulme, P. E., Oksanen, L., & Suominen, O. (2004). Importance of large and small mammalian herbivores for the plant community structure in the forest tundra ecotone. *Oikos*, 106(2), 324–334.
- Olofsson, J., Oksanen, L., Callaghan, T., Hulme, P. E., Oksanen, T., & Suominen, O. (2009). Herbivores inhibit climate-driven shrub expansion on the tundra. *Global Change Biology*, 15, 2681–2693. doi: [10.1111/j.1365-2486.2009.01935.x](https://doi.org/10.1111/j.1365-2486.2009.01935.x)
- Ostrom, E. (2011). Background on the Institutional Analysis and Development Framework. *The Policy Studies Journal*, 39(1).
- Pajunen, A., Virtanen, R., & Roininen, H. (2008). The effects of reindeer grazing on the composition and species richness of vegetation in forest–tundra ecotone. *Polar Biology*, 31(10), 1233–1244.
- Pape, R., & Löffler, J. (2012). Climate change, land use conflicts, predation and ecological degradation as challenges for reindeer husbandry in Northern Europe: What do we really know after half a century of research? *Ambio*, 41(5), 421–434. doi: [10.1007/s13280-012-0257-6](https://doi.org/10.1007/s13280-012-0257-6)
- Prime Minister's Office. (2013). Finland's Strategy for the Arctic Region. URL: <https://vnk.fi/en/arctic-issues/finlands-arctic-policy> (assessed 20 November 2019).
- Rasmus, S., Kivinen, S., Bavay, M., & Heiskanen, J. (2016). Local and regional variability in snow conditions in northern Finland: a reindeer herding perspective. *Ambio*, 45(4), 398–414. doi: [10.1007/s1328015-0762-5](https://doi.org/10.1007/s1328015-0762-5)
- Rasmus, S., Kivinen, S., & Irannezhad, M. (2018). Basal ice formation in Northern Finland snow covers during 1948–2016. *Environmental Research Letters*, 13, 114009. doi: [10.1088/1748-9326/aae541](https://doi.org/10.1088/1748-9326/aae541)
- Rasmus, S., Kumpula, J., & Jylhä, K. (2014). Suomen poronhoitoalueen muuttuvat talviset sää- ja lumiolosuhteet (Changing winter conditions in the Finnish reindeer herding area). *Terra*, 126(4), 169–185.
- Raymond, C., Fazey, I., Reed, M., Stringer, L., Robinson, G., & Evelyn, A. (2010). Integrating local and scientific knowledge for environmental management. *Journal of Environmental Management*, 91, 1766–1777. doi: [10.1016/j.jenvman.2010.03.023](https://doi.org/10.1016/j.jenvman.2010.03.023)
- Reinert, H., & Benjaminsen, T. (2015). Conceptualizing resilience in Norwegian Sámi reindeer pastoralism. *Resilience*, 3(2), 95–112.
- RHA (Reindeer Herders Association). (2017). *Statistics of Reindeer Numbers, 2015–2016*. Rovaniemi: RHA.
- Riseth, J. Å., Tømmervik, H., Helander-Renvall, E., Labba, N., Johansson, C., Malnes, E., ... Callaghan, T. V. (2011). Sámi traditional ecological knowledge as a guide to science: snow, ice and reindeer pasture facing climate change. *Polar Record*, 47(3), 202–217. doi: [10.1017/S0032247410000434](https://doi.org/10.1017/S0032247410000434)
- Ruukki, J. (2016). Reindeer factory farming is an environmental risk. *Helsingin Sanomat*, 19.09.2016. (in Finnish)
- Sandström, P., Pahlén, T. G., Edenius, L., Tømmervik, H., Hagner, O., Hemberg, L., ... Mikael, E. (2003). Conflict resolution by participatory management: Remote sensing and GIS as tools for communicating land-use needs for reindeer herding in northern Sweden. *Ambio*, 32, 557–567.
- Sara, M. N. (2011). Land usage and siida autonomy. *Arctic Review*, 2(2).
- Saravesi, K., Aikio, S., Wäli, P. R., Ruotsalainen, A. L., Kaukonen, M., Huusko, K., ... Markkola, A. (2015). Moth outbreaks alter root-associated fungal communities in subarctic mountain birch forests. *Microbial Ecology*, 69(4), 788–797. doi: [10.1007/s00248-015-0577-8](https://doi.org/10.1007/s00248-015-0577-8)

- Sarkki, S., Heikkinen, H.I., Herva, V.-P., & Saarinen, J. (2018). Myths on local use of natural resources and social equity of land use governance: Reindeer herding in Finland. *Land Use Policy*, 77, 322–331. doi: [10.1016/j.landusepol.2018.05.055](https://doi.org/10.1016/j.landusepol.2018.05.055)
- Sonesson, M. (2001). Ecology of some epiphytic lichens on the mountain birch. In F. E. Wielgolaski (Ed.), *Nordic Mountain Birch Ecosystems* (pp. 63–76). Paris and Parthenon, New York and London: UNESCO.
- Stocks, B.J., Fosberg, M. A., Lynham, T. J., Mearns, L., Wotton, B. M., Yang, Q., ... McKenney, D. W. (1998). Climate change and forest fire potential in Russian and Canadian boreal forests *Climatic Change*, 38, 1–13.
- Tape, K., Sturm, M., & Racine, C. H. (2006). The evidence for shrub expansion in northern Alaska and the Pan-Arctic. *Global Change Biology*, 12, 686–702.
- Tenow, O., Bylund, H., Nilsen, A. C., & Karlsson, P. S. (2005). Long-term influence of herbivores on northern birch forests. In F. E. Wielgolaski (Ed.), *Plant Ecology, Herbivory and Human Impact in Nordic Mountain Birch Forests* (pp. 165–181). Berlin: Springer.
- Tenow, O., & Nilsen, A. (1990). Egg cold hardiness and topoclimatic limitations to outbreaks of *Epirrita autumnata* in northern Fennoscandia. *Journal of Applied Ecology*, 27, 723–734.
- Tømmervik, H., Bjerke, J., Gaare, E., Johansen, B., & Thannheiser, D. (2012). Rapid recovery of recently overexploited winter grazing pastures for reindeer in northern Norway. *Fungal Ecology*, 5(1), 3–15.
- Tømmervik, H., Johansen, B., Riseth, J. A., Karlsen, S. R., Solberg, B., & Høgda, K. A. (2009). Above ground biomass changes in the mountain birch forests and mountain heaths of Finnmarksvidda, northern Norway, in the period 1957–2006. *Forest Ecology and Management*, 257, 244–257.
- Tømmervik, H., Johansen, B., Tombre, I., Thannheiser, D., Høgda, K. A., Gaare, E. & Wielgolaski, F. E. (2004). Vegetation changes in the Nordic mountain birch forest: the influence of grazing and climate change. *Arctic, Antarctic and Alpine Research*, 36, 323–332.
- Turi, E. I., & Keskkitalo, E. C. H. (2014). Governing reindeer husbandry in western Finnmark: Barriers for incorporating traditional knowledge in local-level policy implementation. *Polar Geography*, 37(3), 234–251.
- Turunen, M., Rasmus, S., Bavay, M., Ruosteenoja, K., & Heiskanen, J. (2016). Coping with increasingly difficult weather and snow conditions: Reindeer herders' views on climate change impacts and coping strategies. *Climate Risk Management*, 11, 15–36.
- Uboni, A., Horstkotte, T., Kaarlejärvi, E., Sévêque, A., Stammler, F., Olofsson, J., ... Moen, J. (2016). Long-Term trends and role of climate in the population dynamics of Eurasian Reindeer. *PLoS ONE*, 11(6), e0158359. doi: [10.1371/journal.pone.0158359](https://doi.org/10.1371/journal.pone.0158359)
- Uhlig, C., & Zink, A. (2006). Changes in organic horizon soil properties due to reindeer herding and changing management. In B. C. Forbes, M. Bølter, L. Müller-Wille, J. Hukkinen, F. Müller, N. Gunsley, & Y. Konstantinov (Eds.), *Reindeer Management in Northernmost Europe: Linking Practical and Scientific Knowledge in Social-Ecological Systems (Ecological Studies 184)* (pp. 245–264). Berlin: Springer.
- UNESCO. (2017). Local and indigenous knowledge systems. URL: <http://www.unesco.org/new/en/natural-sciences/priority-areas/links/related-information/what-is-local-and-indigenous-knowledge/> (assessed 24 October 2018).
- Väisänen, M., Yläne, H., Kaarlejärvi, E., Sjögersten, S., Olofsson, J., Crout, N., & Stark, S. (2014). Consequences of warming on tundra carbon balance determined by reindeer grazing history. *Nature Climate Change*, 4, 384–388. doi: [10.1038/NCLIMATE2147](https://doi.org/10.1038/NCLIMATE2147)
- Veijola, P. (1998). Suomen metsärajametsien käyttö ja suojelu (Use and conservation of the tree line forests in Finland). Finnish Forest Research Institute, Research Papers 692, Helsinki, Finland.
- Vikhamar-Schuler, D., Hanssen-Bauer, I., & Forland, E. (2010). Long-term climate trends of Finnmarksvidda, Northern-Norway. Norwegian Meteorological Institute, Report 6, Oslo, Norway.
- Vikhamar-Schuler, D., Isaksen, K., Haugen, J. E., Tømmervik, H., Luks, B., Schuler, T. V., & Bjerke, J. W. (2016). Changes in winter warming events in the Nordic Arctic Region. *Journal of Climate*, 29, 6223–6244.
- Virtanen, R. (2000). Effects of grazing on above-ground biomass on a mountain snowbed, NW Finland. *Oikos*, 90(2), 295–300.
- Vowles, T., Lovehø, C., Molau, U., & Björk, R. (2017). Contrasting impacts of reindeer grazing in two tundra grasslands. *Environmental Research Letters*, 12(3), 34018.
- Vuojala-Magga, T. (2012). Adaptation of Sámi reindeer herding: EU regulation and climate change. In Tennberg M. (Eds.), *Governing the Uncertain: Adaptation and Climate Change in Russia and Finland* (pp. 101–122). Dordrecht, Heidelberg, London, NY: Springer.
- Vuojala-Magga, T., & Turunen, M. (2015). Sámi reindeer herders' perspective on herbivory of subarctic mountain birch forests by geometrid moths and reindeer: a case study from northernmost Finland. *SpringerPlus*, 4, 134. doi: [10.1186/s40064-015-0921-y](https://doi.org/10.1186/s40064-015-0921-y)
- Vuojala-Magga, T., Turunen, M., Ryyppö, T., & Tennberg, M. (2011). Resonance strategies of Sami reindeer herding during climatically extreme years in northernmost Finland in 1970–2007. *Arctic*, 64(2), 227–241.
- Walker, M. D., Wahren, C. H., Hollister, R. D., Henry, G. H. R., Ahlquist, L. E., Alatalo, J. M., ... Wookey, P. A. (2006). Plant community responses to experimental warming across the tundra biome. *Proceedings of the National Academy of Sciences of the USA* 103, 1342–1346. doi: [10.1073/pnas.0503198103](https://doi.org/10.1073/pnas.0503198103)
- Weladji, R. B., Holand, Ø., & Almøy, T. (2003). Use of climatic data to assess the effect of insect harassment on the autumn weight of reindeer (*Rangifer tarandus*) calves. *Journal of Zoology*, 260, 79–85. doi: [10.1017/S0952836903003510](https://doi.org/10.1017/S0952836903003510)
- Wielgolaski, F.E. (2002). Nordic mountain birch forest. In S. Kankaanpää, L. Müller-Wille, P. Susiluoto, & M.-L. Sutinen (Eds.), *Northern Timberline Forests: Environmental and Socio-Economic Issues and Concerns* (Finnish Forest Research Institute, Research papers 862) (pp. 76–90). Helsinki: Finnish Forest Research Institute.